Four-year Performance of *Populus deltoides* Bartr. and some of its Hybrids in Northwestern Ontario

R.E. Farmer Jr., C.L. Palmer, and G.J. O'Reilly
School of Forestry
Lakehead University
Thunder Bay, Ontario

1994

Funding for this report has been provided through the Northern Ontario Development Agreement's Northern Forestry Program

Canadian Cataloguing in Publication Data

The National Library of Canada has catalogued this publication as follows:
R.E. Farmer Jr., C.L. Palmer and G.J. O'Reilly
Main entry under title: Four-year performance of *Populus deltoides* Bartr. and some of its hybrids in Northwestern Ontario
(NODA/NFP Technical report; TR–2)
Co-published by the Ontario Ministry of Natural Resources, Northern Ontario Development Agreement, Northern Forestry Program.
Includes an abstract in French.
Includes bibliographical references.
ISBN 0–662–20746–7
DSS cat. no. Fo29–41/2–1994E

1. Poplar—Ontario—Growth.
2. Trees—Ontario—Growth.
3. Forest management—Ontario.
I. Palmer, C. Lynn (Catherine Lynn), 1960–
II. O'Reilly, G.J.
III. Great Lakes Forestry Centre.
IV. Series: NODA/NFP report; TR–2
SD397.P85F37 1994 634.9'723 C93–099603–8

Catalogue No. Fo29–41/2–1994E
ISBN 0–662–20746–7
ISSN 1195–2334

Copies of this publication are available at no charge from:
Communications Services
Natural Resources Canada
Canadian Forest Service
Ontario Region
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiches of this publication may be purchased from:
Micro Media Inc.
Place du Portage
165, Hotel-de-Ville
Hull, Quebec J8X 3X2

 This report was produced in partial fulfillment of the requirements of Project No. 33020, "Development of Short Rotational Silvicultural Systems for Selected *Populus* and *Larix* in Northern Ontario", under the Research, Development and Applications Subprogram of the Canada–Ontario Forest Resource Development Agreement (1984–1989). Funding for the printing of this publication was made available through the Northern Ontario Development Agreement, Northern Forestry Program.

Farmer, R.E. Jr.; Palmer, C.L.; O'Reilly, G.J. 1994. Four-year performance of *Populus deltoides* Bartr. and some of its hybrids in northwestern Ontario. Nat. Resour. Can., Can. For. Serv., Ont. Region, Sault Ste. Marie, Ont. NODA/NFP Tech. Rep. TR–2. 13 p.

ABSTRACT

Seventy-six clones of *Populus deltoides* Bartr. and its hybrids with *P. nigra* Muenchh., *P. balsamifera* L., and *P. trichocarpa* Torr. & Gray were evaluated for 4 years in two tests near Fort Frances and Thunder Bay (48°N) in northwestern Ontario. The most rapidly growing clones had an average height increment of 1.6 m/year on the better of the two sites (Fort Frances). First-year frost damage to many clones at the Thunder Bay site was the basis for a major clone–site interaction related to different clonal ranks in height on the two sites. Midsummer height increment rate was as high as 5.0 cm/day for some clones. High mid-season elongation rate and the capability of late-summer shoot growth were positively correlated with 4-year total height. Juvenile leaf area, branch characteristics, and phenology were poorly correlated with growth. Twenty of the clones were severely damaged by a canker disease by the end of the fourth growing season; twenty-six were free of disease.

RÉSUMÉ

Soixante-seize clones de *Populus deltoides* Bartr. et de leurs hybrides avec *P. nigra* Muenchh., *P. balsamifera* L., et *P. trichocarpa* Torr. & Gray ont été évalués pendant 4 ans dans 2 stations expérimentales situées près de Fort Frances et de Thunder Bay (48°N), dans le nord-ouest de l'Ontario. Les clones ayant la croissance la plus rapide avaient un accroissement moyen en hauteur de 1,6 m/année dans la station ayant donné les meilleurs résultats (Fort Frances). À Thunder Bay, les dégâts causés par le gel à de nombreux clones pendant la première année ont été à l'origine d'une grande interaction clone–station sur les différentes classes de hauteur des clones dans les deux stations. L'accroissement en hauteur au milieu de l'été pouvait atteindre jusqu'à 5 cm/jour chez certains clones. Un rythme élevé d'élongation à la mi-saison et l'aptitude des pousses à croître à la fin de l'été étaient corrélés positivement avec la hauteur totale après 4 ans. La surface foliaire des jeunes arbres, les caractéristiques des branches, et la phénologie étaient faiblement corrélées à la croissance. Vingt des clones ont été gravement ravagés par une maladie causée par un chancre à la fin de la quatrième saison de croissance; 26 clones étaient exempts de maladie.

TABLE OF CONTENTS

FOUR-YEAR PERFORMANCE OF *POPULUS DELTOIDES* BART. AND SOME OF ITS HYBRIDS IN NORTHWESTERN ONTARIO

INTRODUCTION

Cold-hardy, disease-resistant poplars, which can outperform aspen in terms of volume growth, have the potential for broadening the variety of planting stock available to boreal forest managers. One approach to developing this species might consist of moving selected eastern cottonwood (*Populus deltoides* Bartr.) from the north-central edge of its range to appropriate boreal sites. Hybridization of these adapted selections with selected balsam poplar (*P. balsamifera* L.) might offer further opportunity for simultaneously increasing hardiness and growth. Five clones that are suitable for pilot-scale use at latitudes of up to 49°N in Ontario have been identified via tests (Farmer et al., 1991). In the present study, we continued development of this material by evaluating the hardiness, disease susceptibility, and juvenile growth of 76 clones selected for their potential in the north. In addition, we examined relationships between early morphological and growth characteristics that might be useful in early selection.

METHODS

Material

Following a survey of available and potentially suitable material in the north-central United States and Canada, 76 clones of *Populus deltoides* and its hybrids were selected in 1986 for inclusion in the study; the 68 that survived to the end of the fourth growing season are described in this report (Table 1). Thirteen clones came from long-term clonal tests established in 1981 near Moonbeam, Ontario, by the Ontario Ministry of Natural Resources (OMNR) (Farmer et al., 1991). An additional 37 clones were selected from informal tests at OMNR nurseries at Thunder Bay and Swastika, Ontario. Twenty-four clones were selected from a collection being tested at Grand Rapids, Minnesota, by the University of Minnesota. Two clones were taken from the Lakehead University (Thunder Bay, Ont.) nursery. With the exception of the Minnesota clones, all the material was collected or developed during the 1970s in an OMNR breeding program under the direction of Dr. Louis Zsuffa (University of Toronto). The nomenclature for these clones is that of OMNR.

Sites

The clones were tested at Fort Frances (48°41'N, 93°25'W) and Thunder Bay (48°25'N, 89°20'W), Ontario. The old field sites that were used were plowed and disced in mid-July 1986, then sprayed with glyphosate in mid-August to kill resprouting vegetation. A second discing was carried out in mid-September, and sites were rototilled immediately before planting in the following spring (1987).

The Fort Frances site has a deep, well-drained dark loam of lacustrine origin; it is a prime agricultural soil. The Thunder Bay soil is a deep sandy loam of alluvial origin.

Experimental Design

Four contiguous replications of a randomized complete block design were planted on each site. Each of the four replications contained two ramets of each clone, randomly located and spaced at 1 x 1 m. After the 1987 growing season, one replication at each site was harvested to provide cuttings for a long-term test. Therefore, all results after 1987 are based on three replications at each site.

Establishment and Maintenance

In late March 1987, unrooted 10-cm-long dormant stem cuttings were planted in Spencer–Lemaire containers (750 mL) filled with a 60:40 peat:vermiculite mix that was supplemented weekly with a complete soluble fertilizer (200 ppm, 20:20:20 NPK). The cuttings were grown in a greenhouse until late May, then transferred to a lath-house for several weeks before planting in tests between 8 and 17 June. At this time, new shoots were 10 to 20 cm long. Immediately after planting, test sites were fertilized with 150 kg/ha of nitrogen in the form of ammonium nitrate and 40 kg/ha of phosphorus (superphosphate). The Thunder Bay test site was cultivated with a rototiller and hoes to keep it free of weeds during the first two growing seasons. Only one season of weed control was required at Fort Frances, since crown closure took place during the first growing season. The Thunder Bay site was irrigated once in late June 1987.

Observations

Total height was recorded at the end of each growing season from 1987 (year 1) to 1990 (year 4). In 1987 and 1988, shoot elongation rate and the duration of elongation was assessed by biweekly measurement of the current shoot length of one ramet per clone in each replication.

Table 1. Characteristics of the 68 surviving poplar clones in nursery tests at Fort Frances (FF) and Thunder Bay (TB).

Clone and origin[a]	Height (m) in year 4		Shoot growth rate (cm/day) in 1988				Proportion (% of ramets)			Mean rust rating[b]	No. of branches (TB, 1988)		Branch angle (degrees from vertical), TB, 1987	Bud break (no. days after Apr. 18)	Leaf fall (no. days after Oct. 1)
			July–Aug.		Sept.		Damaged by frost (1987–1988)		Main stem or top dead						
	FF	TB	FF	TB	FF	TB	FF	TB			Sylleptic	Total			
D116, *P. deltoides*, Minn. 45°N	7.13	4.19	3.8	2.5	0.1	0.5	67	100	0	2.0	23	32	48	–	28
D113, *P. deltoides*, Minn. 45°N	7.05	4.55	4.7	2.0	0.2	0.5	0	83	0	3.1	21	36	52	–	29
D105, *P. deltoides*, Minn. 45°N	6.94	4.65	4.0	3.0	0.4	0.8	33	100	0	3.3	15	26	50	–	29
D119, *P. deltoides*, Minn. 44°N	6.9	4.17	4.4	2.4	0.2	0.1	17	83	0	3.5	5	22	53	–	23
D110, *P. deltoides*, Minn. 45°N	6.88	4.96	4.7	2.4	0.2	0.4	0	100	0	2.7	1	24	63	–	22
D112, *P. deltoides*, Minn. 45°N	6.88	4.49	4.0	2.8	0.3	0.6	0	100	16	2.7	29	43	54	–	23
D114, *P. deltoides*, Minn. 44°N	6.75	4.02	4.6	2.7	0.4	0.8	100	100	8	3.7	18	29	62	–	29
DN91, *P. deltoides*, Manitoba	6.74	5.53	4.5	2.5	0.2	0.4	0	50	0	1.0	1	29	71	38	26
DN5, *P. euramericana* cv "Gelrica", Germany	6.71	5.35	2.3	2.3	0.1	0.3	0	100	0	1.0	1	22	60	–	25
DN112, *P. deltoides* X *nigra*, Maple, Ont.	6.67	4.39	4.0	2.4	0.2	0.3	0	100	8	2.9	10	35	54	–	27
D125, *P. deltoides*, Minn. 45°N	6.66	4.47	3.8	1.9	0.5	0.3	0	100	0	1.8	10	32	48	–	23
D118, *P. deltoides*, Minn. 44°N	6.63	3.99	4.8	2.5	0.1	0.1	0	100	0	3.5	12	23	51	–	24
D111, *P. deltoides*, Minn. 45°N	6.41	4.65	4.8	21.0	0.3	0.4	0	83	8	3.7	1	27	55	–	18

(cont'd)

Table 1. Characteristics of the 68 surviving poplar clones in nursery tests at Fort Frances (FF) and Thunder Bay (TB). *(cont'd)*

Clone and origin[a]	Height (m) in year 4		Shoot growth rate (cm/day) in 1988				Proportion (% of ramets)				No. of branches (TB, 1988)		Branch angle (degrees from vertical),	Bud break (no. days	Leaf fall (no. days after
			July–Aug.		Sept.		Damaged by frost (1987–1988)		Main stem or top dead	Mean rust rating[b]					
	FF	TB	FF	TB	FF	TB	FF	TB			Sylleptic	Total	TB, 1987	after Apr. 18)	Oct. 1)
D108, *P. deltoides*, Minn. 45°N	6.28	3.30	4.1	2.6	0.3	0.8	100	100	50	3.3	21	36	52	–	23
D102, *P. deltoides*, Minn. 45°N	6.18	4.23	4.0	1.7	0.1	0.2	33	100	8	3.7	28	42	62	–	29
D120, *P. deltoides*, Minn. 44°N	6.11	2.62	4.1	2.6	0.2	0.3	67	100	41	2.9	10	20	49	–	26
D123, *P. deltoides*, Minn. 44°N	6.10	–	4.1	–	0.2	–	50	–	–	3.2	–	–	–	–	–
D101, *P. deltoides*, Minn. 45°N	6.08	4.35	4.3	2.9	0.1	0.1	17	100	–	3.6	14	30	51	–	27
TACN17, *P.* X *berolineusis*, Quebec	6.08	5.2	3.9	2.5	0.0	0.4	0	17	0	1.0	10	39	48	17	25
D122, *P. deltoides*, Minn. 44°N	6.07	4.24	4.2	2.1	0.1	0.4	0	100	16	4.1	1	19	64	–	20
ANS7, *P.* cv *angulita* X *simonii* , Ottawa	6.06	5.40	4.7	2.3	0.1	0.5	0	33	0	3.1	2	25	67	20	26
DN109, *P. deltoides* X *nigra*, Maple	6.05	4.28	5.0	2.4	0.0	0.3	0	100	0	3.0	1	22	49	–	28
175–5, *P. deltoides*, Minn. 44°N	6.03	4.12	4.3	2.4	0.2	0.3	17	100	0	3.3	5	18	54	–	23
DN184, *P. deltoides* X *nigra*, NEFES	6.03	5.59	4.5	2.9	0.0	0.2	0	0	0	4.7	2	26	64	18	28
DTAC26,*P. deltoides* X *trichocarpa*, Belgium	6.02	4.29	4.4	3.4	0.1	0.6	17	100	24	3.4	20	29	52	–	34
169–4, *P. deltoides*, Minn. 44°N	6.00	–	4.2	–	0.4	–	50	–	0	–	–	–	–	–	–

(cont'd)

Table 1: Characteristics of the 68 surviving poplar clones in nursery tests at Fort Frances (FF) and Thunder Bay (TB). *(cont'd)*

Clone and origin[a]	Height (m) in year 4		Shoot growth rate (cm/day) in 1988				Proportion (% of ramets)			Mean rust rating[b]	No. of branches (TB, 1988)		Branch angle (degrees from vertical), TB, 1987	Bud break (no. days after Apr. 18)	Leaf fall (no. days after Oct. 1)
			July–Aug.		Sept.		Damaged by frost (1987–1988)		Main stem or top dead						
	FF	TB	FF	TB	FF	TB	FF	TB			Sylleptic	Total			
DN41, *P. euramericana*, Newfoundland	5.95	4.69	4.3	2.4	0.2	0.2	0	83	0	2.2	2	36	56	–	26
DN160, *P. deltoides* X *nigra*, Maple, Ont.	5.93	3.31	4.2	1.7	0.4	0.7	17	100	25	3.4	5	16	45	–	27
171–1, *P. deltoides*, Minn. 44°N	5.92	3.28	4.1	1.9	0.2	0.5	33	100	33	3.3	6	14	48	–	27
D121, *P. deltoides*, Minn. 45°N	5.82	4.49	4.1	2.8	0.1	0.2	33	100	8	4.3	8	27	55	–	25
TACN1, *P.* X *berolinensis* cv "Berlin", Saskatchewan	5.71	5.40	4.2	2.8	0.0	0.3	0	33	8	1.0	18	44	45	23	25
DN154, *P. deltoides* X *nigra*, Maple, Ont.	5.68	–	3.9	2.5	0.2	0.3	0	100	33	2.7	19	32	51	–	26
DN42, *P. euramericana*, Newfoundland	5.66	4.33	3.8	1.8	0.2	0.4	17	83	0	2.4	1	27	50	–	29
D208, *P.* cv *angulata* X *deltoides*, NEFES	5. 62	5.84	4.8	3.5	0.0	0.0	0	0	0	4.5	1	23	63	21	24
DTAC19, *P.* cv *angulata* X *trichocarpa*, NEFES	5.59	5.22	4.5	2.7	0.0	0.5	0	0	0	4.5	1	27	62	24	28
180–1, *P. deltoides*, Minn. 44°N	5.57	dead	3.9	2.1	0.1	0.2	0	83	58	3.2	9	23	48	–	22
188–1, *P. deltoides*, Minn. 45°N	5.55	3.80	4.3	1.7	0.0	0.1	0	17	17	3.8	4	27	64	38	20
DTAC24, *P.* cv *angulata* X *trichocarpa*, USA	5.41	5.86	4.3	3.3	0.0	0.1	0	0	0	4.5	2	29	66	20	22
Z1, *P. euramericana* cv "Spreewald apple", Germany	5.40	4.02	4.3	1.3	0.1	0.2	17	100	17	2.8	6	21	43	–	29

(cont'd)

Table 1. Characteristics of the 68 surviving poplar clones in nursery tests at Fort Frances (FF) and Thunder Bay (TB). *(cont'd)*

Clone and origin[a]	Height (m) in year 4		Shoot growth rate (cm/day) in 1988				Proportion (% of ramets)			Mean rust rating[b]	No. of branches (TB, 1988)		Branch angle (degrees from vertical), TB, 1987	Bud break (no. days after Apr. 18)	Leaf fall (no. days after Oct. 1)
			July–Aug.		Sept.		Damaged by frost (1987–1988)		Main stem or top dead						
	FF	TB	FF	TB	FF	TB	FF	TB			Sylleptic	Total			
JAC30, *P.* X *jackii*, Manitoba	5.36	3.88	4.2	2.4	0.0	0.2	0	0	0	3.8	2	33	54	22	24
193–5, *P. deltoides*, Minn. 45°N	5.36	4.40	3.8	2.1	0.0	0.1	0	100	0	3.6	5	33	51	–	22
176–5, *P. deltoides*, Minn. 44°N	5.33	3.94	4.1	2.4	0.1	0.2	0	100	8	2.9	17	36	46	–	26
D103, *P. deltoides*, Minn. 45°N	5.31	3.96	4.2	2.0	0.1	0.1	0	100	34	4.7	6	26	59	–	19
DN48, *P. euramericana*, Quebec	5.28	2.70	3.8	2.2	0.1	0.1	0	100	17	3.6	6	16	53	–	–
D195, *P. deltoides* cv "Walker"; Saskatchewan	5.14	3.93	4.2	2.5	0.0	0.2	0	0	0	3.8	3	30	55	22	24
DTAC20, *P.* cv *angulata* X *trichocarpa*, NEFES	5.07	4.75	3.7	2.1	0.1	0.4	0	0	8	4.4	0	27	54	20	31
JAC16, *P. jackii*, Newfoundland	5.06	4.72	3.6	1.9	0.4	0.9	0	83	0	1.8	3	27	55	18	35
DTAC21, *P.* cv *angulata* X *trichocarpa*, NEFES	5.02	4.87	4.5	2.5	0.0	0.2	0	0	33	4.8	1	24	64	18	24
DTAC18, *P.* cv *angulata* X *trichocarpa*, NEFES	4.95	5.06	4.4	2.8	0.0	0.1	0	0	8	4.3	0	25	66	18	21
JAC31, *P. jackii*, Manitoba	4.76	4.81	4.0	2.7	0.0	0.0	0	0	0	3.8	1	20	51	15	20
D190, *P. deltoides* cv "Brooks #4", Alberta	4.75	4.86	3.9	3.0	0.0	0.1	0	0	17	3.6	1	23	49	15	20
DTAC29, *P. deltoides* X *trichocarpa*, Belgium	4.48	dead	3.9	1.8	0.4	1.0	67	100	75	2.8	15	19	42	–	36
DTAC22, *P.* cv *angulata* X *trichocarpa*, USA	4.40	5.22	3.8	2.9	0.0	0.1	0	0	34	4.5	1	24	53	19	29
D198, *P. deltoides* cv "Augustifolia", Sask.	4.40	4.25	4.0	1.8	0.1	0.3	0	33	41	4.2	3	29	59	38	31

(cont'd)

Table 1. Characteristics of the 68 surviving poplar clones in nursery tests at Fort Frances (FF) and Thunder Bay (TB). *(concl.)*

Clone and origin[a]	Height (m) in year 4		Shoot growth rate (cm/day) in 1988				Proportion (% of ramets)								
			July–Aug.		Sept.		Damaged by frost (1987–1988)		Main stem or top dead	Mean rust rating[b]	No. of branches (TB, 1988)		Branch angle (degrees from vertical), TB, 1987	Bud break (no. days after Apr. 18)	Leaf fall (no. days after Oct. 1)
	FF	TB	FF	TB	FF	TB	FF	TB			Sylleptic	Total			
DTAC53, *P. deltoides* X *balsamifera*, Maple, Ont.	4.35	3.63	4.1	2.4	0.0	0.2	0	0	58	4.4	0	17	56	27	23
D191, *P. deltoides* cv "Brooks #6", Alberta	4.31	5.53	4.1	2.8	0.0	0.1	0	0	8	3.9	1	24	54	15	20
JAC25, *P. jackii*, Quebec	4.30	2.95	4.0	2.4	0.0	0.1	0	0	50	4.9	0	21	53	19	20
DTAC16, *P.* cv *angulata* X *trichocarpa*, NEFES	4.24	4.90	3.9	2.7	0.0	0.1	0	0	17	4.6	0	26	59	19	23
DTAC17, *P.* cv *angulata* X *trichocarpa*, NEFES	4.09	5.20	4.4	2.8	0.0	0.1	0	0	17	4.4	0	28	62	19	27
DTAC50, *P. deltoides* X *balsamifera*, Maple, Ont.	4.00	3.59	3.8	1.9	0.1	0.0	0	17	66	4.5	0	19	55	23	20
SER2, *P. deltoides* X *nigra*, England	3.93	4.08	3.9	1.7	0.1	0.2	0	33	25	4.0	2	26	57	38	30
D207, *P. deltoides* cv "Brooks #1", Alberta	3.91	5.90	4.2	3.0	0.1	0.7	0	0	25	1.1	6	30	43	17	32
JAC12, *P. jackii*, Ontario	3.84	3.47	3.4	2.0	0.0	0.0	0	0	25	3.4	2	20	63	23	25
DTAC25, *P.* cv *angulata* X *trichocarpa*, USA	3.81	4.40	3.9	1.9	0.2	0.4	17	83	25	3.7	0	22	55	20	29
DTACN1, *P. candicans* X *berolinensis*, Quebec	3.74	3.89	3.9	2.2	0.0	0.2	0	50	50	2.5	6	33	60	31	28
DTAC23, *P. angulata* X *trichocarpa*, Quebec	3.57	4.94	3.9	3.2	0.0	0.1	0	0	33	4.6	0	23	57	20	20
PCHEY, unknown	3.15	5.78	4.2	2.7	0.2	0.8	0	0	49	1.0	3	24	41	18	26
POP856, *P.* cv *angulata* X *balsamifera*, Maple, Ont.	3.06	4.70	4.0	3.4	0.0	0.2	0	0	58	4.4	0	19	52	18	17

[a]NEFES = USDA Forest Service, Northeastern Forest Experiment Station

[b]Rust rating refers to the scale (from 0 to 5) described in the *Methods* section of this report.

In September 1987, leaf area of each plant was determined in the Thunder Bay test for three ramets of each of 24 clones that represented the range of mean clone heights. For this purpose, a total of 239 leaves, representing the range of leaf sizes in the test, were picked from ramets of 71 clones. Leaf length, width, and area were determined and several regressions of leaf area in relation to leaf dimensions were computed. A simple linear regression of area in relation to length x width gave the best estimate of area. This was used to determine leaf area on the 24 sampled clones: leaf area = 0.339 + 0.676 (L x W). All leaves on the three ramets per clone were then measured and total leaf area per tree was computed.

Branch characteristics were recorded at the end of the 1988 growing season in the Thunder Bay test. These included (1) the total number of primary branches on 1987 growth, (2) the number of sylleptic branches formed on the main stem during the 1988 growing season, and (3) the angle (from the vertical) of branches on 1987 main-stem growth. For the latter purpose, the angles of three adjacent branches at the stem's midpoint were measured.

In early September 1987, observations of the leaf rust caused by *Melampsora medusae* Thüm. were made in both tests. For this purpose, one of the following ratings was assigned to each of four leaves on each plant, one leaf in each cardinal direction:

1 = 0–10% of leaf surface covered with uredia
2 = 11–40% of leaf surface covered with uredia
3 = 41–70% of leaf surface covered with uredia
4 = 70–100% of leaf surface covered with uredia
5 = 100% of leaf surface covered with uredia, and presence of necrosis.

In September 1988, these observations of infection were repeated in the Thunder Bay test.

In the fall of 1987, the date on which 90% of leaves had fallen was recorded for all ramets in the Thunder Bay test. In the spring of 1988, the date of bud break was observed in the Thunder Bay test for terminal buds on main shoots of ramets undamaged by frost.

Frost damage (as evidenced by necrotic shoot tips) was recorded for all ramets in both tests in early June 1988 and at subsequent height measurements. During the September 1989 and 1990 height measurements, the occurrence of canker disease (probably *Septoria* sp.) on each ramet was recorded.

RESULTS

Growth

Because of intensive first-year culture, survival was essentially 100% in 1987. Average height by the end of the 1990 growing season (4 years) was 5.54 m at the Fort Frances site and 4.42 m at Thunder Bay. Characteristics of the 68 surviving clones are presented in Table 1. Clonal mean heights ranged from 2.61 to 7.13 m at Fort Frances and from 2.01 to 5.90 m at Thunder Bay. Comparisons of 1990 clonal means using analyses of variance for individual sites indicated that differences of about 1.4 and 0.9 m were statistically significant (P=0.05 level) at Fort Frances and Thunder Bay, respectively.

Combined analyses of height and diameter data from the two sites indicated that, in addition to significant clonal and site differences, there was a significant clone–site interaction throughout the study. This interaction, which is manifested in a change in clonal rank between sites, was also evaluated by examining correlations of clonal means for height in the two tests. The coefficients for these correlations were 0.77, 0.61, 0.49, and 0.09 for 1987, 1988, 1989, and 1990, respectively, indicating a major shift in rank over time. Clonal rankings also shifted within sites, mostly between 1987 and other years, as evidenced by the correlations between years of clonal means for height (Table 2).

Table 2. Correlations between clonal height in one year and height in subsequent years for the two study sites.

	Fort Frances			Thunder Bay		
	1988	1989	1990	1988	1989	1990
1987	0.87	0.70	0.73	0.59	0.31	0.05
1988	–	0.82	0.79	–	0.86	0.72
1989	–	–	0.92	–	–	0.89

Many of the differences and changes in rankings were due to the frost damage to some clones at Thunder Bay after their first growing season. The resulting reduction in height, which shifted clonal rank, did not occur at Fort Frances, where there was less frost damage.

Phenology

Phenology was observed only in the Thunder Bay test. In 1987, the mean number of days from 1 October until 90% leaf drop occurred ranged from 16 (17 October) to 36 (6 November) for individual clones, and clonal means were evenly distributed over the defoliation period. Clonal differences of about 4 days and greater

were statistically significant at the P=0.05 level. Clonal means for the number of days from 18 April 1988 until bud break (i.e., leaf tips at least 5 mm long) ranged from 15 (3 May) to 38 (26 May) for clones that were undamaged by freezing during fall and winter. Bud break for damaged clones was not evaluated, because 1 to 100 cm of their main shoots were dead and only lower lateral buds resumed growth. There was little relationship (r = 0.14) between leaf fall and bud break dates for individual clones. Neither were there significant correlations between leaf fall date and height in either 1987 or 1990. There was, however, a weak (r=-0.40) but significant negative correlation between bud break date and 1990 height.

Freezing Damage

Freezing damage was evaluated at both sites by recording the length of dead stem on each damaged plant in 1988.

In the Thunder Bay test, 49 of the 76 clones exhibited some frost damage (Table 1), with clonal means for 1988 height increment losses ranging from 1 to 105 cm. In 1989 and 1990, 32 and 5 clones, respectively, had some damage to their shoot tips, but the resulting height loss was negligible. The *Populus deltoides* clones from Minnesota were most severely damaged. Twenty-one clones were damaged in 1988 at Fort Frances, where the Minnesota *Populus deltoides* clones were again most susceptible. In 1989 and 1990, there was minor shoot damage on only five clones.

Shoot Elongation Rate and Pattern

The pattern of shoot growth for clones that represented the range of clonal means for final height on both sites in 1988 is illustrated in Figure 1. The maximum growth rate occurred between mid-July and mid-August in both 1987 and 1988, with this high rate beginning slightly later in 1987, probably due to a delay imposed by the recovery from planting shock. During the periods of most rapid elongation, growth rates averaged 2.0 to 2.6 cm per day at Thunder Bay (Table 1). Higher average rates (up to 4.0 cm/day) were observed at Fort Frances, where one clone of *Populus deltoides* X *nigra* (DN 109) exhibited a growth rate of 5.0 cm/day between 27 July and 8 August 1988. Analyses of variance, completed for individual tests by year, indicated that clonal differences of about 0.5 cm/day were significant at the P=0.05 level during periods of rapid growth. In 1988, when periodic measurements were made until October, nearly all clones continued elongation into early September at both sites, with some exhibiting growth rates of 0.1 to 1.0 cm/day from 1 to 15 September.

There was no correlation between clonal means for growth rates during the middle of the growing season and September ($r < 0.20$ and nonsignificant). On the other hand, the highly variable clonal means for September growth rate at Fort Frances and Thunder Bay were modestly correlated (r = 0.75). Correlations between 1990 clonal mean height and shoot elongation rate in midsummer (27 July to 8 August) and autumn (29 August to 20 September) of 1988 were also examined. Although correlation coefficients for this relationship were positive and statistically significant at Fort Frances, they were low (r=0.47, 0.46). At Thunder Bay, midsummer shoot growth rates were positively correlated with height (r=0.56), but late-season rates were not related to height.

First-year Leaf Area

Average individual-tree leaf area in 1987 varied widely among clones, and main-stem leaves were larger than those on branches (Table 3). This variation in leaf size and large clonal differences in the number of leaves per ramet resulted in wide (range = 2,703 to 6,514 cm^2) clonal variation in total leaf area in the 24-clone sample. The correlation of clonal means for 1987 height with total leaf area, though statistically significant (P=0.05 level), had a coefficient of only r=0.42. First-year leaf area of these 24 clones growing in Thunder Bay was not related to their 1990 height, but it was weakly correlated with their 1990 height (r=0.34) at Fort Frances. Since nine of the studied clones lost their early dominant position at Thunder Bay because of frost damage, the difference in this relationship is understandable.

Branch Characteristics

Clonal means for the total number of branches per ramet ranged from 20 to 42 at the end of 1988 (Table 1). Clonal means for the number of sylleptic branches in 1988 varied significantly from none to more than 20 branches (on five of the *P. deltoides* clones from Minnesota). Although clonal means for branch angle ranged from 40° to 71°, more than half were between 50° and 60°. Branch angle was unrelated to the number of branches or height. The correlations of 1990 height with total number of branches in 1988, total number of branches in 1987, and number of sylleptic branches in 1988 had coefficients of 0.27, 0.47, and -0.16, respectively.

Disease Susceptibility

Mean clonal ratings (see *Methods*) for the occurrence of *Melampsora* rust in 1987 and 1988 ranged from 1.0 to 4.8 (Table 1). Rating differences of about 1.0 were statistically significant. In 1987, ratings at the same

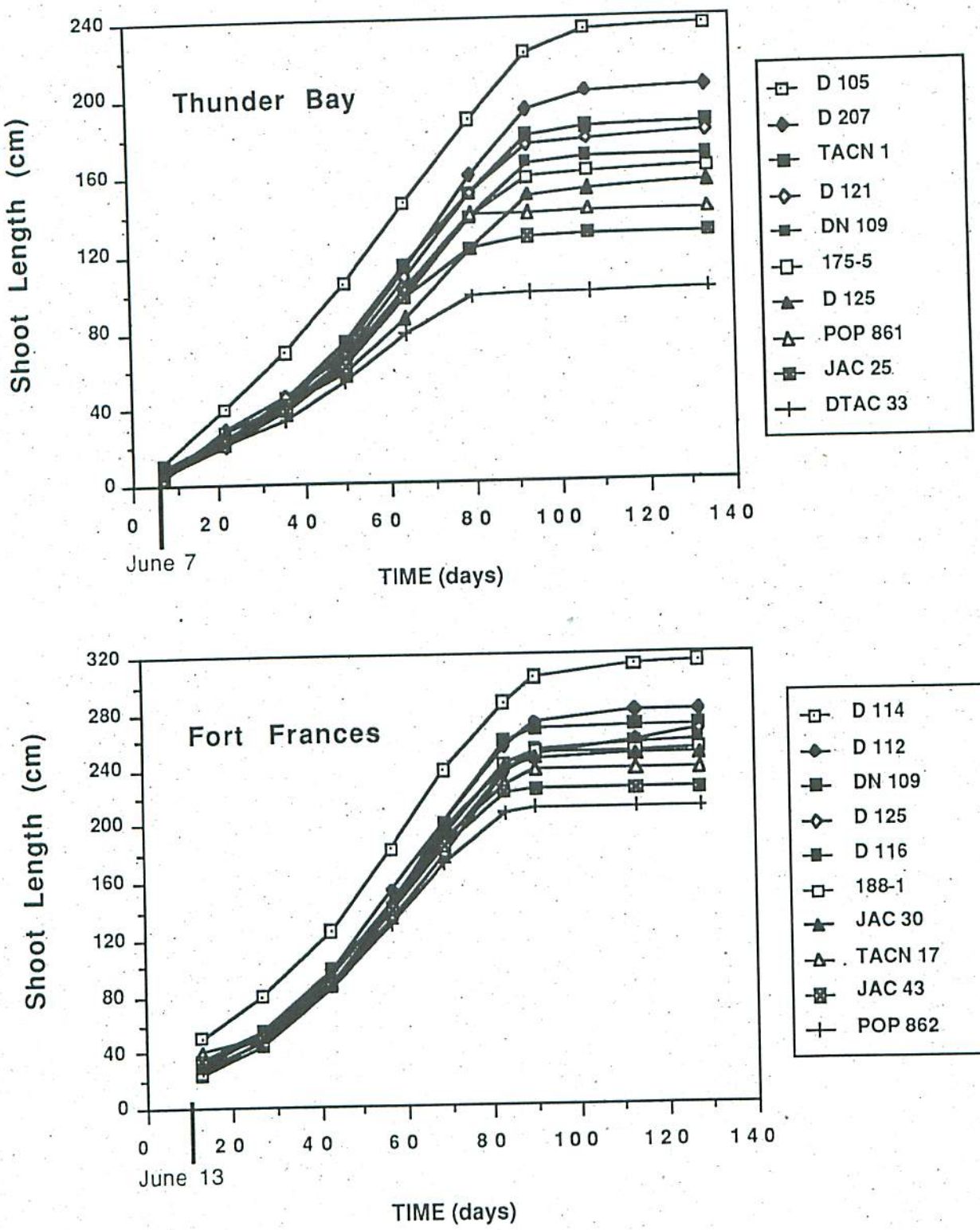

Figure 1. Pattern of 1988 shoot growth for clones representing the range of performance on the Thunder Bay and Fort Frances sites.

Table 3. First-year leaf area and shoot characteristics of 24 poplar clones representing the range of first-year height.

Clone	Leaf area (cm^2)				Ratio of leaf area on main stem to whole plant	Height (m)	Number of	
	Single leaf		Total area					
	Whole plant	Main stem only	Whole plant	Main stem only			Branches	Leaves
ANS7	59	88	4,723	2,477	0.52	1.11	23	80
D103	26	51	3,104	2,174	0.70	1.27	20	119
D105	32	67	5,082	3,039	0.60	1.56	11	158
D108	29	66	5,574	2,656	0.48	1.46	15	192
D110	38	52	2,703	1,722	0.64	1.25	23	71
D112	22	63	5,989	2,285	0.38	1.28	14	272
D113	25	59	6,514	2,129	0.33	1.25	15	260
D114	31	65	6,266	2,537	0.40	1.22	11	202
D122	37	58	3,394	2,534	0.75	1.28	18	91
D125	35	68	4,339	2,809	0.64	1.23	22	123
D190	47	51	3,862	1,653	0.42	0.81	22	82
D207	29	46	2,949	1,585	0.54	0.96	24	101
DN48	34	58	2,874	1,792	0.62	0.72	10	85
DN91	44	51	2,959	2,280	0.77	1.15	28	67
DTAC16	103	117	4,108	3,959	0.96	1.10	26	40
DTAC18	87	88	3,067	3,067	1.00	1.10	25	35
DTAC24	68	98	4,914	3,424	0.70	1.37	27	72
DTAC26	56	117	8,440	3,089	0.37	1.17	9	150
DTACN1	31	52	5,375	2,011	0.37	1.13	27	173
JAC12	50	78	3,798	2,003	0.53	0.77	18	76
JAC30	36	52	3,320	2,122	0.64	1.16	31	92
POP863	41	54	2,743	1,562	0.57	0.89	19	67
SER2	38	56	3,379	2,046	0.61	1.01	24	89
TACN1	15	24	2,965	755	0.25	0.80	26	197
Mean	42	66	4,288	2,321	0.54	1.12	20	102

time in early September were generally higher in the Fort Frances test, indicating a greater level of infection at this site. Only six clones were uniformly free of rust at both sites in 1987 and at Thunder Bay in 1988: DN5, DN91, JAC16, PCHEY, TACN1, and TACN17. Twenty-seven clones were severely infected (ratings>4.0) in both years and places. Clonal mean rust ratings were modestly correlated among years and sites (r=0.70 to 0.85) and with late-season shoot elongation rate (r=-0.48 to -0.52). However, there was no relationship between rust infection and 1990 height.

The other major disease noted in the tests was a stem canker, probably caused by *Septoria* sp., which caused the death of some clones, especially in the DTAC and JAC series. At Fort Frances, nearly all clones had ramets with at least a minor canker infection by 1989; cankers were less abundant in the Thunder Bay test. These cankers on the main stem were small at Fort Frances, and in most clones, did not increase in size between 1989 and 1990. In the majority of clones, there was no mortality or major damage associated with the cankers by 1990.

DISCUSSION

At the Fort Frances site, the top 20% of clones in terms of growth included *P. deltoides* from Minnesota and three *P. deltoides* X *P. nigra* hybrids (DN91, DN5, DN112). With the exception of minor stem cankers (which were found on practically all material) these clones are still free of serious disease other than *Melampsora* rust. In contrast, the top 20% of clones at Thunder Bay were mostly hybrids. Though *P. deltoides* clones performed better than hybrids during the first season of growth at Thunder Bay, most of them never recovered their relative position after losing height as a result of frost damage to terminal shoots in the fall and winter of 1987–1988. The close (1 m) spacing probably accentuated their loss of position. With the

exception of three clones (D207, PCHEY, DTAC 22), the top 20% of the population at Thunder Bay is so far free of mortality and major cankers. Observations after the 1988, 1989, and 1990 growing seasons indicate that the phenology of 3- and 4- year-old plants is such that frost damage has not been a problem at either site.

A few of the clones in this study have been included in other formal tests in the boreal forest zone. Clones D191, D207, and TACN1 were all 6 to 7 m tall and disease-free after 7 years of growth near Kapuskasing, Ontario (40°20'N) (Farmer et al. 1991). In a Newfoundland (49°N) study on four sites, Khalil (1984) noted an average 4-year height of 120 cm for DN5, which ranked tenth in a population of 32 clones. The best clones in his test grew less than 2 m in 4 years, suggesting that site and/or culturally related limiting factors prevented a good test of clonal growth potential. Clone DN5 in our study grew 1.6 m per year at Fort Frances and 1.3 m per year at Thunder Bay.

Other trials, in Ontario and Quebec, have been completed in the Great Lakes–St. Lawrence forest region south of the boreal forest. In perhaps the most extensive of these (68 clones in fifty-three 10-year trials), Popovich (1982) noted that the most promising clones grew 1.3 m per year on good sites in Quebec. In southern Ontario, where OMNR has tested more than 400 clones of various origin and parentage, the best clones have averaged 1.8 m per year during the first 7 years (Anon. 1983, Zsuffa et al. 1977). The two best *P. deltoides* clones (D113, D116) at our Fort Frances site grew 1.8 m per year. Thus, selected material adapted to the southern edge of the boreal forest may have the capability of early growth almost equivalent to the best growth observed at latitudes 45° to 47°N.

This potential for good height growth is related to both rapid shoot elongation during the grand period of growth in midsummer and the continuation of elongation well into September at 48° to 49°N. The maximum elongation rates observed are equivalent to those observed in *P. deltoides* at locations much farther south (e.g., Minckler and Woerheide 1968). Although positive correlations between shoot elongation characteristics and 4-year total height were modest, these shoot growth components, which can be easily measured on juvenile material, appear worthy of further examination in tests leading to selection. Other characteristics such as leaf area and branching, which may be positively related to growth, are reflected in elongation rates, but are more expensive to measure. In general, early indirect selection in this sort of population is still not as reliable as direct selection for growth from among large numbers of clones. Moreover, correlations between growth and such characteristics as branching, leaf area, and phenology had generally low coefficients.

However, one simple and potentially effective indirect selection technique may be to select clones that take full advantage of late summer and early fall because of their less conservative photoperiodic response, yet are still frost hardy. A number of clones in our study exhibited this capacity for late-season growth, which is under relatively strong genetic control. If the predictions of climate modelers for a warming trend (due to a greenhouse effect) prove true, it is likely that material with such a photoperiodic response may substantially outperform local material, which ceases elongation in response to mid-August photoperiods at 49°N. Thus, a moderating fall climate would allow use of *P. deltoides*, which may be only marginally hardy in the boreal forest region at present.

Although the juvenile growth and hardiness of many clones in this study promises good productivity in the boreal forest region, their disease susceptibility remains a reason for caution. To date, 40% of the tested clones have one or more ramets that have been killed by a canker disease. The top clones have exhibited no mortality in the study to date, but experience elsewhere suggests that a number of tests that will last over an entire rotation should precede extensive use of the clones.

ACKNOWLEDGMENTS

This work was supported by a grant under the Canada–Ontario Forest Resource Development Agreement. The authors thank Boise–Cascade Canada for its support of the test at Fort Frances, Ontario, and Marie Vella for her technical assistance.

LITERATURE CITED

Anon. 1983. New forests in eastern Ontario. Hybrid poplar. Ont. Min. Nat. Resour., Toronto, Ont. Sci. Technol. Series Vol. 1. 336 p.

Farmer, R.E. Jr.; Palmer, C.L.; Anderson, H.W.; Zsuffa, L.; O'Reilly, G. 1991. Nine-year outplanting test of cottonwood and hybrid poplar clones in northwestern Ontario. Tree Planters' Notes 42(2):49–51.

Khalil, M.A.K. 1984. The potential of poplars in the boreal regions. I. Survival and growth. Silv. Genet. 33(1):1–8.

Minckler, L.S.; Woerheide, J.D. 1968. Weekly height growth of cottonwood. For. Sci. 14:212–222.

Popovich, S. 1982. Performance of hybrid poplars in Quebec ten years after planting. Dep. Environ., Can. For. Serv., Ste-Foy, Que. Inf. Rep. LAU–X–44. 23 p.

Zsuffa, L.; Anderson, H.W.; Jaciw, P. 1977. Trends and prospects in Ontario's poplar management program. For. Chron. 53:195–200.